THE HIDDEN IMPLICATIONS OF FORCE CHANGES

Dr. Rolf Clark

National security planners naturally draw on insights and experiences when making decisions. Past examples, national doctrine, organizational realities, threat development, technical knowledge, and fiscal analysis are used. This article explores another useful insight, one on the dynamics of system change. The system of interest concerns force levels. An increase or a decrease in force levels can lead to production dynamics that are unforeseen, and sometimes even impossible to meet. During the buildup of the 1980s, for example, the intention to achieve a 600-ship Navy, and related increases in aircraft forces, led to procurement levels that were ultimately unattainable within the budgets available. Industry could not accelerate production levels enough to meet force level increases largely because unit costs rose dramatically as demand stressed supply. The intent is to see why such production difficulties arise. The theory will present two important concepts in dynamic thinking. The first concerns the "accelerator," a concept which leads to instability: to bottlenecks and excesses. The second involves the distinction between "stocks" and "flows." Stocks and flows explain why accelerators occur. These concepts are not completely intuitive.

We see accelerators in almost every aspect of life. They apply to driving a car, to inventory control, and to the acquisition of forces. Each experiences system dynamics. These short-term "transient state" dynamics occur when a system is changed from one state to another—when force levels are raised as they were in the 1980s, or reduced as they have been in the 1990s. Further, stocks and flows are the building blocks for understanding systems in change.

The "first-order effects" of system changes require crude examples, and certainly adjustments would be made in real life that smooth out the first-order changes. Yet first-order effects by definition dominate system change. Foreseeing the dynamics helps us plan force changes.

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THE ACCELERATOR: DRIVING YOUR CAR

The accelerator principle is at work when you drive your car. Say you're doing 50 mph on a straightaway and want to accelerate to 60. You first step on the gas firmly, and as you reach 60 mph, ease back to steady up. To increase speed by 20 percent you may increase the flow of fuel by 300 percent (depending on how fast you accelerate) and then at 60—the new steady state—use only slightly more fuel than you first did at 50 mph. Speed only rises, but fuel flow goes up and down.

While speeding up—in the "transient state"—the fuel flow changes much more than the velocity of the car. That's an accelerator. The same principle applies to acquisition: force levels rise, but procurement goes up and then down.

STOCKS AND FLOWS

Procurement is a flow; the force level is a stock. Flows change faster than stocks. That's the accelerator relationship again.

Accelerators depend on the relationship between a system's stocks and its flows. A stock is an accumulation—an inventory, a summation, something that has been collected over time. It is measured in units like "aircraft," or "tons," or "boxcars." The water in a bathtub (gallons) is a stock. The inventory of cars at a Chevrolet dealer is a stock.

Flows, on the other hand, are measured in units like "aircraft per year," or "tons per week," or "boxcars per day." Flows feed into and out of stocks. The water pouring through the faucet (gallons per minute) is an inflow; leaving through the drain, an outflow. New cars arriving at the dealer per week is an inflow; car sales per week, an outflow. Stocks have value at a point in time; flows only have value over a time interval. One can take a still photograph of a stock; but a seeing a flow requires a video recording.

In national finance, a stock would be the federal debt while a flow would be the annual federal deficit. Plant and equipment in a corporation would be a stock while investment and depreciation would be flows. Stocks are on a firm's balance sheet; they are assets and liabilities. Flows are on the income statement; they are the annual revenues and expenditures.

In national defense, flows are system deliveries, personnel recruitments, purchases of spare parts, shipments to and from inventories, and force inactivations. Stocks are force levels, personnel, inventories, systems in process of being produced, and systems in repair. The interactions between stocks and flows lead to temporary inventory shortages, delivery delays, force inadequacies, and pipeline instabilities.

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Logical Implications

All systems can be modeled in terms of stocks and flows. Modeling systems using stocks and flows is an aspect of system simulation, and of "system dynamics" in particular. We cannot treat the discipline in detail here (see Forrester, 1968), but even with a simple system, several factors can be acknowledged.

If system stocks last a very long time, then the flows that maintain them will be small. If assets have a 30-year life, like Navy ships, in peacetime only about 1/30th of them leave each year and thus only 1/30th of them need to be replaced.

As a corollary, if the flows are small compared to the stock, then the stock changes slowly. The small flows mean long-lived force assets require lengthy periods of time to evolve into new configurations. The steady state in shipbuilding occurs about 50 years after a change, when the fleet has finally turned over.

Consider national investment. If national savings per year (a flow) is low, we will invest less and the economy cannot change rapidly. Countries like Japan and Korea, with much higher savings rates than the United States during the 1970s and 1980s, were able to shift their economies to new technologies far faster.

The dynamics are different for shorter lived systems. Information age systems like electronics and software reach obsolescence after four or five years, and have faster turnover rates. They consequently experience less severe transient dynamics, though they cost more to sustain at required levels.

Stocks and Flows Are Pervasive

Stocks and flows and their associated accelerators are everywhere. Fortunes are made or lost because of them.

In 1970 there was a corn blight, and prices increased dramatically. Some traders bought pork futures, thinking they would profit when the price of pork rose. Pigs are corn-fed and a rise in corn prices would mean pork prices should also rise. This is indeed true in steady state, but not in the short-term transient state. In fact, pork dropped in price for six months after corn prices rose. Why? Pig farmers, knowing they could not afford the higher feed prices, slaughtered their breeding stock, causing an accelerated short-term flow of pork to the marketplace. The flow caused a glut, and instead of pork prices rising, they fell. A year later pork was indeed at far higher prices, but in the interim the traders had lost heavily (Meadows, 1970).

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In the mid-1970s, long before the oil price reached its 1980 peak, a graduate student at the Massachusetts Institute of Technology reportedly advised his family—who owned oil tankers—to sell their fleet. He had observed that the flow of tankers in production was too large compared to the stock of existing tankers, and there would soon be excess tankers at sea. He was right. The utilization rate of the world's tankers fell from 120 percent in 1972 to 70 percent in 1979 to 40 percent in 1982. This lowered

the value of tankers, which soon were selling at far less than their building cost. The family reentered the market at its bottom, and by 1989 the utilization rate was again near 90% (Randers, 1984; Bakken, 1992).

SURGE DYNAMICS

We have argued that if the stock of assets is to be increased rapidly—as in mobilization or even surge—then the procurement inflow must increase dramatically. It is time to explore the accelerator and its dynamics more quantitatively. Consider Figure 1.

Suppose you want to increase an aircraft fleet from 80 to 100 in five years and that aircraft last 10 years. The eventual 100-aircraft force will then have 1/10th, or 10 of the aircraft retiring each year. To stay at 100 aircraft, 10 units need to be procured each year to replace those retiring. The original 80 aircraft fleet required only 8 be built each year. But it is misleading to conclude that to go from a force of 80 to 100 means raising aircraft production from 8 to 10. Such steady-state thinking is incomplete. To raise the stock of aircraft from 80 to 100 requires adding 20 aircraft. To do this in five years means producing four extra aircraft each of the five years, or increasing the annual production flow from 8 to 12, a 50 percent increase as shown. At the end of the five-year buildup, since none of the 20 new aircraft need replacement, the production flow drops to 10. To increase the force assets by 25 percent over five years means the flow of aircraft being produced needs to suddenly increase by 50 percent—truly a building boom. A bust period, however, follows. This inevitable boom-to-bust dynamic is the accelerator at work.

This simple analysis has ignored attrition, which could be accommodated but

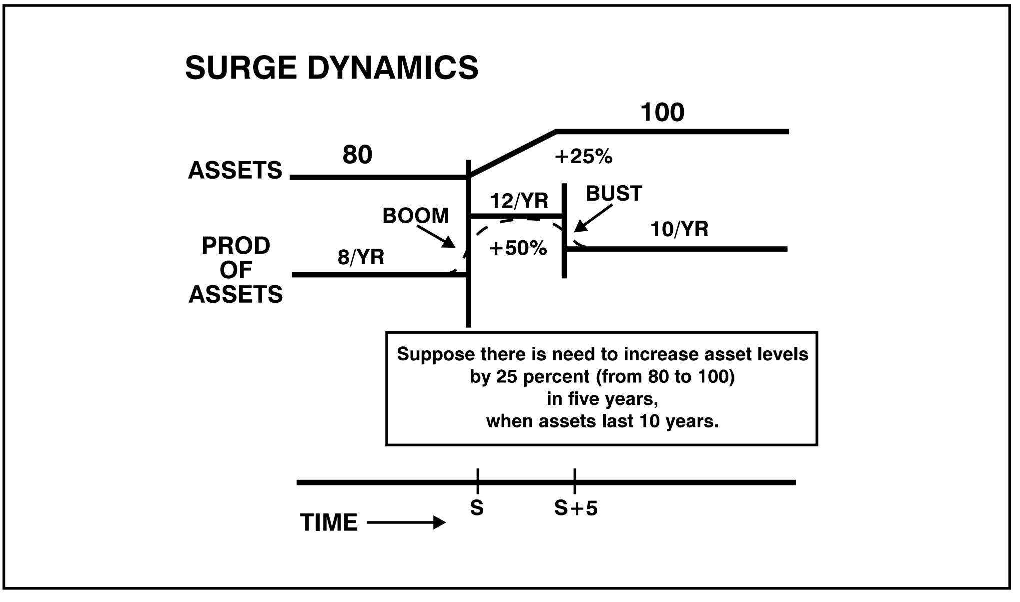

Figure 1. Surge Dynamics—Production of Assets

does muddy the discussion. In a peacetime buildup, attrition would not be a factor. In war it would significantly increase the dynamics as first production would need to accelerate even more to accommodate the attrited units. Then by ceasing hostilities, there would be an even larger drop as attrition ceases the same time reduced force levels are needed. Thus the accounting would involve more arithmetic, but the concept would be the same.

Another caveat is that the above has assumed units are only bought or inactivated. They might also be updated through modernization. This again complicates the analysis beyond the discussion intended here, though modernization can also be accommodated. One wants a computer simulation to do so. Equipment upgrades extend the life of systems, and are a way to ameliorate sudden increases in procurement by spreading expenditures out over time. One then needs to maintain information on system age, and prepare for eventual block obsolescence.

Furthermore, adjustments in the analysis can be made for the possibility of cannibalizing inactivated systems. Cannibalizing means less need for replacement. This would reduce the accelerated production during buildup, but the bust period associated with downsizing would be even more severe as equipments would be older, on average, due to the cannibalized parts.

Such qualifiers provide the second- and third-order considerations. The dotted line in the above indicates there will be ways to smooth out the severity of the first-order impacts discussed so far, though the attrition aspect actually amplifies them.

The Attraction of Maintenance

Precisely because of the severe dynamics associated with production, firms often diversify into maintenance of assets. Maintenance is closely related to force levels, which vary far less than procurements. If a firm—such as an aircraft engine manufacturer—can augment its production business with maintenance services, its financial fortunes will be more stable. From automobile agencies to aircraft engine manufacturers to shipyards, maintenance business becomes a stabilizing force.

Upstream Production has Amplified Dynamics

Returning to our simple example to see what more can be drawn out, the 50 percent sudden increase in the flow of production, compared to the 25 percent increase spread over five years in the stock of assets, is a large difference. Production flows translate into jobs and raw materials. The first point, then, is that even small and gradual increases in force levels will mean large sudden increases in jobs and materials.

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There is more. Upstream production—that further up the manufacturing process—will experience even greater dynamics. Consider the Figure 2, which expands Figure 1.

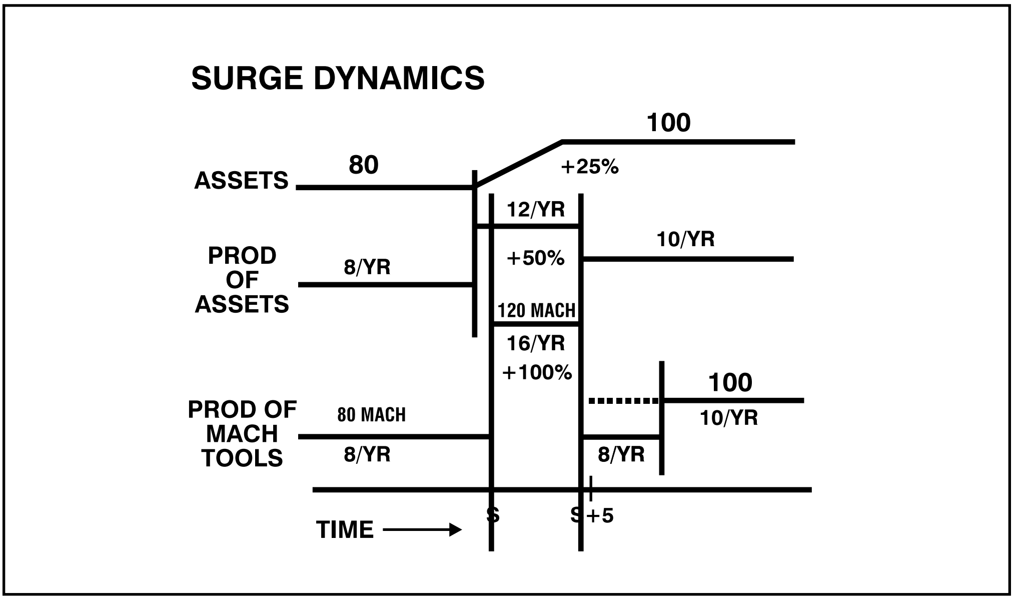

Figure 2. Surge Dynamics—Upstream Production

Suppose that it takes on average 10 production "machines" (metal benders, cutters, lathes, welders, computers, etc.) to produce one aircraft per year. Then a factory needs 80 machines to produce eight aircraft per year. If these "machines" also last 10 years on average, then eight machines need to be procured by the factory each year to replace those machines wearing out. During the buildup, however, production is raised to 12 aircraft per year, and thus about 120 machines are needed. To get from 80 to 120 machines in five years the factory must buy 16 machines per year for five years—eight to replace those ending their useful life plus another eight each year for five years to get 40 more machines. While aircraft assets have increased 25 percent and aircraft production 50 percent, machine production must increase 100 percent, from 8 to 16. After reaching the desired level of machines, machine tool production experiences a bust period, followed by a recovery when steady state is finally reached. Upstream production dynamics are severe.

Machine tools are further up the production stream, as they produce the machines that produce the assets. In 1945, J. A. Krug, then Chairman of the War Production Board, reported on the criticality of machine tools during the World War II: "The timing varied for different products and different industries, but in general the acute shortage as the defense effort first got underway was in the facilities… plant, equipment, and above all, machine tools" (War Production Board, 1945).

Capital equipment sectors continue to experience wide swings. Between 1981 and 1983 the U.S. machine tool sector lost 60 percent of its annual new orders (AMT, 1992–93). Machine tools are only one example of the upstream production fac-

tors. Plant and equipment, commercial real estate, as well as factories, mills, and refineries, also are driven by such dynamics.

Clearly, planners will want to anticipate such impacts on the industrial base when force level changes are planned.

Long- Versus Short-Lived Assets

Ships and oil equipment and real estate have long lives. Industries producing goods with shorter life spans, like electronic equipment, will experience less severe production dynamics. Since they decay more rapidly, their flows are relatively large compared to their stocks. They "turn over" faster. As a result their production booms and busts are more contracted in time, and less severe in amplitude.

Let's translate the above 80 to 100 aircraft example into an analogous $80 million to $100 million electronic system. If the electronic components last only five years, the $80 million program will require 20 percent of its value, or $16 million of procurement per year, to retain its original value. Increasing the system's value to $100 million in five years means increasing procurement budgets by $4 million per year—from $16 million to $20 million—a 25 percent increase. Thus while aircraft that lasted 10 years required a 50 percent increase in procurement to raise assets by 20 percent, the electronic system with assets lasting only five years required only a 25 percent increase in procurement to obtain the same proportional growth in the same time. Systems with shorter life spans require less severe dynamics during change. The information age, with shorter system lives as well as more agile production, may experience less severe system dynamics.

A Word on Budgets

We have seen that procurement, and therefore procurement budgets, change dramatically when force levels change. Operations and maintenance (O&M) budgets and personnel budgets, on the other hand, do not experience the same dynamics. They are closely related to force assets, and change primarily as force levels change. Since 1974 the defense procurement budget has varied by an average of 12 percent in year-to-year changes. The overall budget itself has varied year by year by only five percent. The changes to O&M and personnel budgets, making up most of the residual after procurement, is deducted from the budget, and must logically vary much less. The average annual change of ownership budgets has been between one and two percent.[1]

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Understanding system dynamics should help improve budget development, especially regarding the long-term needs for ownership budgets associated with the force levels.

[1] Some care must be taken in thinking about this. Planned O&M budgets often swing widely, but executed O&M budgets do not, for they ultimately support force assets, and assets do not change rapidly.

Defense Builddowns and Decelerators

Opposite dynamics from the above are at work during force level reductions. Procurement falls far more than force levels. For example, by 1993 military aircraft assets had decreased about 30 percent from 1989 levels. Yet the military engine sales of U.S. engine producers had decreased 70 percent.[2]

This is logical. Just as you ease up on the gas to slow down your car, and then increase gas flow again once you reach your desired lower speed, so aircraft engine sales must drop dramatically, and then rebound somewhat, once the military stabilizes at lower force. Then, analogous to the force increase dynamics, production will partly rebound as the new steady state is reached. This rebound should be anticipated. For example, the backlog of orders for military aircraft engines actually rose in 1995, after dropping steadily for the previous six years as aircraft inventories fell. Aircraft levels themselves did not increase in 1995, but they stopped their rapid decline. This relative stabilization led to the increase in backlog (AIAA, 1996–97).

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What is Needed

Understanding acquisition and logistics dynamics requires stock and flow thinking. The above samples are simplified, and more complex problems need consideration. Yet the stock-flow logic and what it tells us needs its place in the policy makers' set of analytic tools. Such considerations will help managers see that inventories in the spare parts pipeline will often be far from intended levels—sometimes too high, sometimes far too low. Deliveries suffer, lead times expand, and prices rise. In the 1980s buildup, lead times on many items soared, and unit prices rose dramatically with the surge. More recently, decelerators have forced reductions in defense facilities and jobs. The argument here is that the dynamics are predictable.

A more subtle insight is embedded in the accelerator-decelerator paradigm. An initial cutback in force levels leads to a reduction in production as we have seen, which leads to a cutback in orders for production equipment (machine tools) as we have also seen. But if this production capacity cutback is done without looking ahead to the recovery phase of the decelerator, then there will not be enough production capacity to recover when needed. In the aircraft example, when production stabilizes, there may not be enough machine tools to produce the new demand and machines must first be used to produce more machines. This "bootstrap" problem is endemic to accelerators.

Nobel prize winner Herbert Simon's claim in the 1950s that the human mind cannot solve the complex problems of the real world is less true today. His principle of "bounded rationality" still holds, but we can do far more exploration with computers than we could with the mathematics

[2] Data provided by Aerospace Industries Association, Washington, DC.

of 1957 (Simon, 1957). System dynamics such as discussed here are now easily modeled and should be implemented. This would require a reasonable simulation effort the captures the necessary intricacies of force level procurement and support.

For now, incorporating the accelerator logic in policy thinking is beneficial. Computer simulations that quantify the interrelationships between systems and determine the magnitudes and timing of these dynamics will naturally follow. The modeling mathematics are state of the art. The policy implications are important. Planners need to ensure that transient state dynamics are adequately captured in the policy making process.

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